AGARDograph 63

Radio Navigation Systems

FOR AVIATION AND MARITIME USE

A Comparative Study

Technical Editor

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CONTENTS

2.08. DECCA

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1. GENERAL INTRODUCTION

The Decca hyperbolic radio navigation system with four ground stations was first used in 1944 and is based on proposals put forward by O'Brien.[1] The four ground stations of a Decca chain are arranged in a star configuration with the Master station located in the centre, and the three Slave stations (purple, red, green) are located at a distance to the Master station of approximately 120–200 km. Similar ideas were put forward by Meint Harms in a German Letters Patent of 1930.[2] A high positional accuracy is obtained at ranges from the Master station of 300–400 km. The effective range of the Decca system is at least 450 km. On the border of the coverage the radial error is less than 8 n.m. (approximately 15 km) at a 95 per cent probability.

The Decca system is based upon the principle of phase comparison. Thus the ground transmitters can be operated without modulation. Only a very narrow receiver pass-band is required ($\pm$ 25 c/s with the Mark 8 receiver, and $\pm$ 10 c/s with the Mark 10 receiver, which is designed as a superhet).

Since no airborne (shipborne) transmitter is required for obtaining a fix, the Decca system can accommodate an unlimited number of users.

Each Decca chain requires four fixed frequencies (with Mark 10 five fixed frequencies). The frequency ranges allocated for this purpose by international agreement, viz. 70.087–70.583 kc/s, 84.105–85.900 kc/s, 112.140–114.533 kc/s, 126.157–128.850 kc/s for normal operation, and 114.943–117.397 kc/s for Mark 10 operation, can accommodate 21 Decca chains. The same frequency group may be used by another chain, if the distance between the two Master stations is approximately 2.300 km, with the frequencies of the Master stations of two different chains being separated by 5 c/s only and the frequency distance of the Slave stations being harmonically related to each other.

The range throughout the coverage is independent of the height, and, thus the system may be used by both shipping and aviation, since a frequency of approximately 100 kc/s is used. Position fixing above the ground stations is also essentially independent of the height (for the special measures taken, see section 4).

Various receiver models are available for airborne or shipborne use respectively. In marine use 2 or 3 fine decometers are read normally to obtain a fix. The values read define hyperbolic lines of position which are overprinted on conventional marine charts. To determine the approximate position for the 1- time, the combined coarse decometer is read. In aviation, the Flight Log is used which displays the position pictorially on charts which are still distorted geographically. However, the degree of distortion

can be reduced in most cases by selection of suitable combinations of hyperbolae. Moreover, a distortionless flight log is being developed.

Further applications of the flight log are discussed in section 2.

Systems using phase comparison techniques become ambiguous when the length of the base line exceeds half the wavelength $\lambda_v/2$ of the comparison signal. When the receiver is moved along the base line by a distance of $\lambda_v/2$, the phase angle of the reference signal is turned by 2π; the decometer indicating the phase angle performs one full revolution. According to the reference frequency, 18, 24 or 30 lanes of a base width of $\lambda_v/2$ form a zone whose width is approximately 10 km on the base line. The position of a lane within a zone is determined by phase comparison of a frequency identical for all zones of a chain (lane identification).

When the Mark 10 receiver is used, the ground stations must transmit an additional frequency, which allows zone identification within five adjacent zones. Moreover, the technical development of the equipment includes a semi-automatic lane identification facility.

Since the total width of five zones is at least 50 km, the residual ambiguity is insignificant from the operational point of view. It should always be possible to resolve this ambiguity by navigational aids other than Decca (dead reckoning, radio direction-finding).

In order to solve the problem of feeding the positional data to the automatic pilot, developments are under way to design a flight log from which appropriate signals can be derived.

The Decca system is also employed in surveying operations both on land and at sea by the use of mobile Decca stations.

One of these mobile stations is the Decca HI-FIX system (high-frequency, high-accuracy fixing). For literature see p. 101.

When aerials which avoid electrostatic charging are used, the Decca system is not easily susceptible to interference because of the long-time constant of the indicating instrument (decometer). Atmospherics usually cause substantially faster phase shifts, and their duration normally is limited to only 0.1 sec, whereas the fast rotation of the decometer pointer takes 0.5 sec.

In order to use the Decca receiver also in conditions of severe interference, such as may occur in the proximity of a thunderstorm, the Decca receiver can be equipped with a device which ensures that the decometer continues to operate on the speed data obtained before the beginning of the interference condition (repeater unit).

A transistorized Mark 10 receiver is being developed.

2. SYSTEM DESCRIPTION[3-7,13,14]

A Decca chain consists of three pairs of transmitter stations of which one—the central Master station—is common to each pair. The Slave stations of a chain are located at the corners of a 120° star configuration. Thus an optimum coverage is obtained with a radius of at least 450 km from the Master station (Fig. 1). The lines connecting the Master station with the Slave stations—the base lines—are normally 120–160 km, and in extreme cases 200 km, in length. The ground stations of a pair of transmitters *A* and *B* (Fig. 2) transmit unmodulated r.f. waves having the frequencies

mf and nf, which are synchronized by their common subharmonic f. The transmissions are received at a field point P, where they are multiplied by

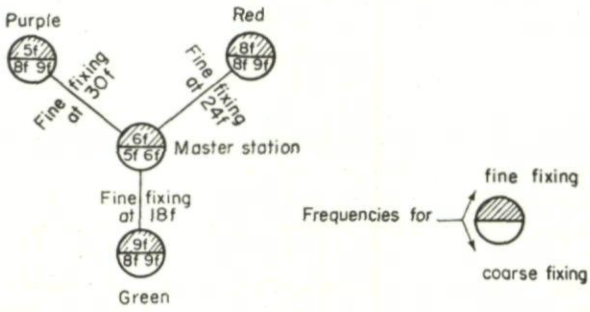


Fig. 1. Layout of the ground stations of a Decca chain with the frequencies assigned for fine and coarse fixing

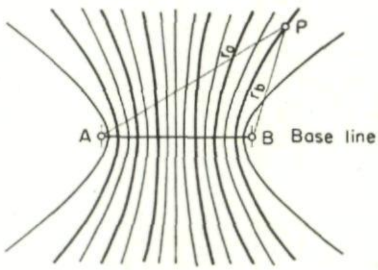


Fig. 2. Hyperbolic pattern

the factors n or m respectively so that two identical frequencies $m \times n \times f$ are produced whose phase difference ϕ then is measured. The phase difference as measured at any point is dependent only upon the difference $r_a - r_b$ under conditions of constant velocity of propagation and, hence, it is constant along a hyperboloid of revolution having the foci A and B.

The following equation applies:

$$\phi = \frac{2\pi}{\lambda n,m}(r_a - r_b)$$

where $\lambda_{n,\,m}$ is the wavelength of the virtual reference frequency $n \times m \times f$. Assuming the coverage on the surface of the earth of the Decca chain under consideration is regarded as plane, the transmission described above produces a virtual hyperbolic pattern in the receiver after frequency multiplication (Fig. 2). The length of the base line between two hyperbolae of equal phase angle difference is $0.5\lambda_{n,\,m} = c/2 \times n \times m \times f$.

Frequency multiplication by m or n respectively is required, for otherwise no separation in the receiver would be possible of the electromagnetic waves transmitted by A and B, since the unmodulated synchronized reference frequencies $n \times m \times f$ are transmitted simultaneously.

When the receiving equipment described above is moved over the hyperbolic grid, the phase-angle changes by 360° while the receiving equipment is moved from one hyperbolae to the next. The phase-angle meter (decometer) indicates only the exact line of position within that area between two hyperbolae which is known as lane. This determination of the line of position is called " fine fixing ". When the receiver is moved out of an identified lane, a lane identification is possible by counting the number of lanes traversed. This procedure, however, is applicable only when the position is known immediately before entering the coverage of a Decca chain.

With the ground station layout in Fig. 1 and the transmitted frequencies given in the upper half of the circles representing the transmitters, which are derived synchronously from the common subharmonic f, three virtual hyperbolic patterns can be derived, whose " fine fixing frequencies " are

$18f$ (green hyperbolic grid)
$24f$ (red hyperbolic grid)
$30f$ (purple hyperbolic grid)

The subharmonic f is allocated the range of 14.018–14.316 kc/s. For instance, with $f = 14.166$ kc/s and a velocity of propagation c of 299.250 km/sec, the transmitted frequencies, the reference frequencies and the lane width on the base lines show the following typical values:

	Transmitted Frequencies	
	(*kc/s*)	(*m*)
Master station	85.000	3521
Red Slave station	113.333	2640
Green Slave station	127.500	2347
Purple Slave station	70.833	4225

Lane Width on Base Line (*m*)		*Reference Frequencies*
Red	440.074	340.000
Green	586.765	255.000
Purple	352.059	425.000

The frequency groups issued by Decca are shown in the Table 1 on page 97.

The position is defined by the intersection of two hyperbolae. The positional accuracy is increased with the angle of intersection approaching 90° and decreasing lane width. There is always a sufficient number of hyperbolae intersecting at right-angles available within the coverage of the four transmitters of a chain in any azimuthal direction from the Master station.

Moreover, outside the transmitters new tertiary contours may be derived by adding and subtracting different hyperbolic patterns. Such tertiary contours intersect with the primary hyperbolae largely at right-angles (Fig. 3). This results in optimum combinations for pictorial display purposes (Fig. 4) for the various effective ranges of a Decca chain. The phase angle

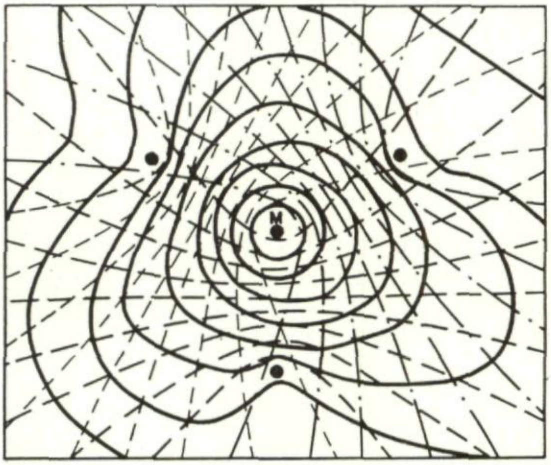


Fig. 3. Primary hyperbolae and tertiary contours of three pairs of transmitters

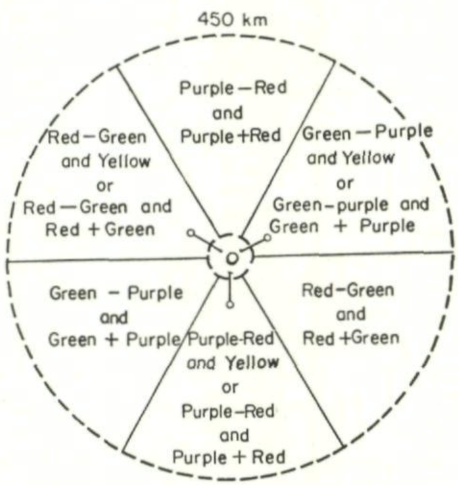


Fig. 4. Combinations for optimum angle of intersection

of each hyperbolic pattern, which is measured separately, can be displayed on three different instruments, the fine fixing decometers, whose outer circular scale is divided into lanes and whose inner circular scale is divided into 1/100 of a lane. The indication is by two separate pointers (see Fig. 5). Since the average lane width on the base line is approximately 500 m, the accuracy of indication is approximately 5 m. The lanes are numbered

according to the assigned multiplication (lane number) and grouped together into zones:

red $24f$, from 0–23,
green $18f$, from 30–47,
purple $30f$, from 50–79.

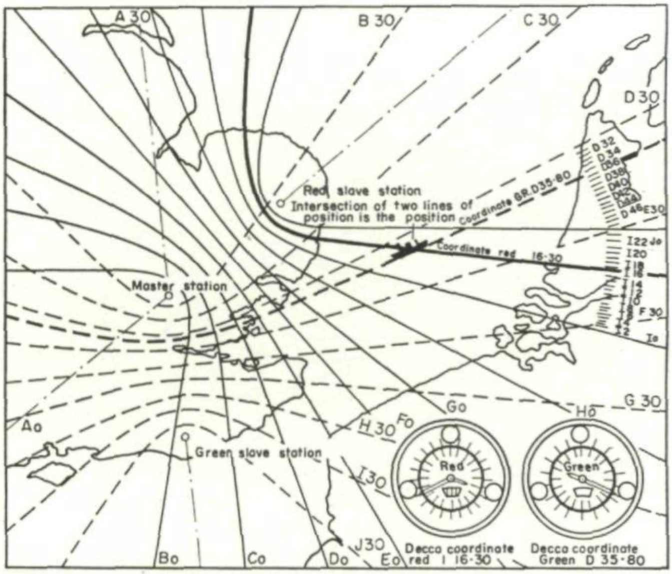


Fig. 5. Lines of position of the red and green hyperbolic patterns of the position of a ship and their display on the respective decometers

The zones of each of the three hyperbolic patterns are denoted by capital letters:
The zone number is equal to:

$$\frac{\text{base line length}}{\text{lane width} \times \text{lane number}} = 2 \times \frac{\text{base line length}}{\text{fundamental frequency } (= c/f)}$$

Lane Identification (Coarse Fixing)

A further facility is provided for lane identification within a zone. Since the range of unambiguity of the zone width is equal to half the wavelength $c/2f$ on the base line with the very-low frequency f of approximately 14 kc/s being allocated, the transmission and, in particular, the reception of these signals becomes difficult because of the low effective height of the receiving aerial. Therefore, each station transmits in addition to its fine fixing signal a lane identification signal by a second transmitter but over the same aerial. The frequency of the lane identification signal differs by the fundamental frequency f from the fine fixing signal. The lane identification signal is transmitted at specified intervals. The Master station cooperates sequentially with each Slave station, thus avoiding confusion. The receiver derives two difference frequencies f from every two frequencies of the stations, $5f$, $6f$, or $8f$, $9f$ respectively. The phase relation of the former is then compared. The zone width on each base line of the above example is 10.562 km. The

ambiguity of the position is reduced to 1/25 by the lane identification process. Thus there will be only 20 ambiguous readings on the base line of 200 km.

This ambiguity is further reduced to 1/5 by another zone identification accomplished in the Mark 10 receiver by means of a reference frequency of $0.2f$. Thus the ambiguity factor is reduced to four within each hyperbolic pattern of a Decca chain.

The transmission cycle provides for the transmission of one lane identification signal for each hyperbolic pattern within each minute. For this purpose the Master station transmits at the beginning of each full minute a signal on the frequency $6f - 60$ c/s, which initiates the red lane identification. This initial signal is transmitted for 1/12 sec. During the following half-second, the Master station transmits simultaneously $5f$ and $6f$ from the same transmitting aerial (see Fig. 1). The red Slave station transmits $8f$ and $9f$, while the transmissions of the purple and green Slave stations are interrupted. The green Slave station, which will be the next station to perform the lane identification, receives the frequencies $5f$ and $6f$ and, after mixing, the frequency $1f$ is used for controlling the phase-locked subharmonic f from which again the commonly transmitted frequencies $8f$ and $9f$ are derived.

The signal on the $6f - 60$ c/s frequency operates a switching circuit on all receivers operating in the coverage of the Decca chain. This switching circuit then switches the receivers for the next half-second so that they derive two reference frequencies f from the four frequencies $8f$, $9f$ and $5f$, $6f$ received. The phase shift of the two reference frequencies indicates the lane identification on a coarse-fixing decometer. In this way approximately 14.5 sec are left until the green lane identification cycle is initiated. During this period the lane identification displayed by the red decometer (lane 0–23) can be checked. After the lane identification period of 0.5 sec all stations change over to the normal condition of fine fixing. At the beginning of the 15th second of each minute, the Master station transmits a signal on the frequencies $6f + 60$ c/s for a period of 1/25 sec. This initiates the green lane identification, which takes 0.5 sec and which is accomplished in the same way as the red lane identification, with the lane identification frequencies given in Fig. 1. At the beginning of the 30th second of each minute, the Master station transmits for a period of 1/12 sec the double frequencies $6f - 60$ c/s and subsequently for 1/25 sec the frequency $6f + 60$ c/s, and thus initiates the 0.5 sec period of the purple identification, which is accomplished as described above. Normal fixing is then accomplished for the rest of the minute, then the new lane identification cycle begins. Figure 5 illustrates the lines of position of the red and green hyperbolic patterns together with the respective decometer indications of a position. The small pointer indicates the line of position within a lane, the large pointer indicates the line of position within a zone, and the letter visible in the small window indicates the zone.

The Decca Receiver[8]

Figure 6a illustrates the block diagram of a receiver during the fine fixing procedure.[3] After amplification and multiplication, the phase angles of $30f$, $18f$ and $24f$ are determined in a four-diode discriminator,

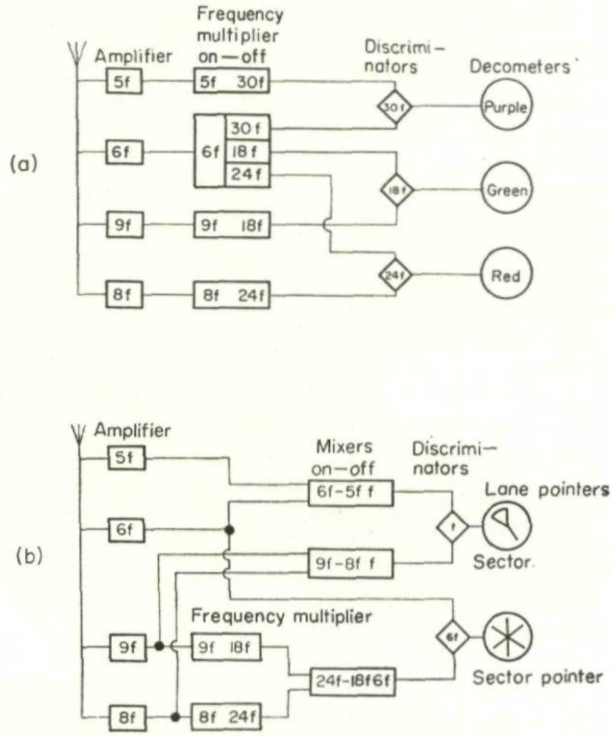


Fig. 6. *Block diagram of a Decca receiver*
(*a*) *during fine fixing*
(*b*) *during coarse fixing*

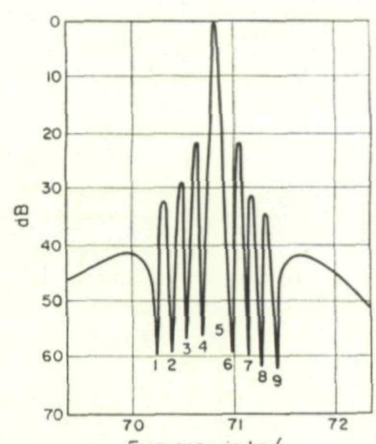


Fig. 7. *Frequency response of the input filters of a Decca receiver tuned to frequency 5*

whose amplified d.c. outputs are proportional to the sine or cosine respectively of the phase angle measured. These outputs are fed to the field coils of the decometer. In order to prevent variations in the phase angle during reception, the capacitances of the receiving aerial are compensated carefully, manually operated devices are provided for controlling and compensating phase-angle variations in the amplifier circuits and the connected circuits, which may be caused by temperature fluctuations. Each of the four receiver channels is provided with crystal filters, which are tuned to the respective Decca chain by the main switch. The crystal filters of the chains operating on adjacent frequencies act as rejector circuits, whose attenuation of the adjacent frequencies is 50–60 dB (see Fig. 7).

From 1949 onwards Decca chains were provided with a lane identification system. Figure 6b illustrates a block diagram of the necessary receiving equipment. In order to improve the lane identification, the frequency $6f$ is derived from the frequencies $8f$ and $9f$ after frequency multiplication. The frequency $6f$ is compared with the frequency transmitted by the Master station. The phase angle difference of the frequency $6f$ is indicated by a six-armed vernier pointer (indicator) on the lane identification meter so geared that one of the six arms indicates the correct lane. The lane identification meter is provided also with a concentrically-mounted sector indicator which selects the correct arm of the six. In this way the lane identification accuracy is improved by a factor of 6 compared with the comparison of the two derived subharmonics f.

The Decca Flight Log[8]

Various models of flight logs are used, which plot on a chart the track flown. The flight log stylus is controlled by the phase-difference indicated by two decometers or, when tertiary contours are employed, by three decometers. Thus it records intersections of hyperbolic patterns with other hyperbolic patterns, or with tertiary contour patterns respectively. Therefore, the charts used must be distorted in such a manner compared with geographical charts that the families of curves selected intersect at right-angles on the charts. The distortion of the geographical charts thus caused is a disadvantage, whose negative influence can be reduced, however, by selecting suitable combinations of hyperbolae (see Fig. 4). The decometer signals are combined correctly in the flight log computer after the families of curves to be used have been selected. These signals are amplified to such an extent in torque amplifiers that they can be used for driving directly the chart and the stylus, whose motions are at right-angles. The movement of the converter provided after the torque amplifier follows the input phase shift at an accuracy of 1/200 of the width between the fine fixing hyperbolae. Simplicity of manipulation is mandatory in airborne equipment which is to be used by the pilot. Therefore, efforts are made to provide an automatic flight log. The Mark 10 receiver, where the setting of the stylus is acomplished semi-automatically, is a remarkable improvement.

The Mark 10 receiver is described in detail below on page 90.

When appropriate flight log charts are used, continuous operation is possible on longer flights without resetting of the stylus.

High-speed aircraft flying in the vicinity of a thunderstorm might traverse a lane so quickly that it is not counted because of the atmospheric noise.

This avoided by an electro-mechanical flywheel facility (repeater unit) provided in some Decca equipment, for instance with the Mark 8 receiver. The repeater unit is arranged between the receiver and the indicating instrument, where it performs the two following functions, which are highly important for high-speed aircraft:

(1) In conditions of high atmospheric noise, which may simulate rapid changes in phase angle, this unit prevents the indicator from jumping or repeating a lane.

(2) When the strength of the received signal is reduced for a brief period, the receiver is switched off automatically. The flight log then is controlled by the repeater unit. The maximum admissible duration of failure depends upon the quality of reception prior to the failure. When reception was satisfactory prior to failure, the Mark 10 receiver can bridge interruptions of up to 40 sec, and older receiver models of up to 10 sec.

The electro-mechanical control circuit described can be adapted to various speeds and is quite useful in special surveying operations.

The atmospherics occurring in airborne reception of low frequencies are of two kinds:

(*a*) Static charging of the aircraft, which is reduced by suitable discharge facilities on the aircraft.

(*b*) Charged raindrops. For protection against this type of interference, an " anti-static " aerial has been developed, which, as a rule, consists of a vertical rod, whose diameter is approximately equal to the cross-section of a wing, and at whose leading edge a fairing is attached, which protects the receiving element proper from raindrop pulses. Another type of " anti-static aerial " of reduced size is incorporated in the stabilizing fin of the rudder (" suppressed aerial "). The most modern form of the " anti-static aerial " is the " shovel aerial " attached to the lower part of the fuselage.

The Mark 10 *Receiver*[3]

The increased speed and the increased number of aircraft demanded an early solution by the Decca system of the following requirements:

(1) The reliability at night-time of the lane identification on the fringes of the coverage must be improved.

(2) Automation of the lane identification process to relieve the pilot and for correction of the lane identification after severe atmospherics.

(3) Possibility of zone identification within a range of at least 40 km in diameter.

These three requirements are satisfied by the Mark 10 receiver.

For Mark 10 operation, the transmission schedule of the ground stations had to be altered. But in spite of the alteration, earlier receiver models can still perform their functions of position fixing.

For lane identification with Mark 10 the four ground stations transmit

simultaneously a sequence of signals on the frequencies $5f$, $6f$, $8f$ and $9f$ synchronized with the subharmonic f. In order to render possible a zone identification within five zones a signal on the frequency $8.2f$ is also transmitted.

While one of the four ground stations transmits these five lane identification frequencies simultaneously from the same aerial, the transmitters of the other three stations are switched off. The Mark 10 receiver, which has been prepared by previous signals (for instance, for green lane identification), receives from the green Slave station all the above five frequencies according to a fixed time schedule. It derives the common subharmonic f from $5f$,

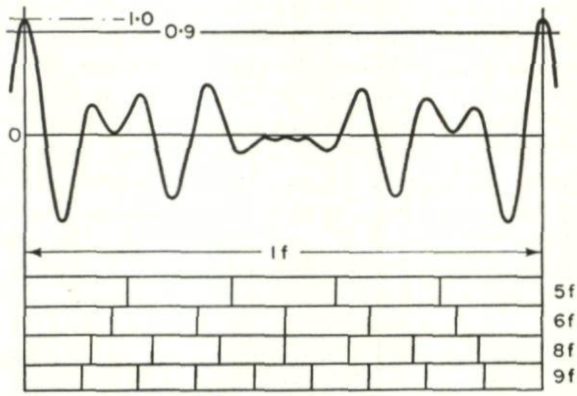


Fig. 8. Superposition of the frequencies $5f$, $6f$, $8f$ *and* $9f$ *in Mark* 10 *operation*

$6f$, $8f$ and $9f$. A continuous oscillator is phase-locked by this subharmonic. Furthermore, the frequency $0.2f$ is derived by mixing, which synchronizes in phase the green zone identification oscillator. Subsequently, the transmission from the Master station is received and the Mark X oscillators of the frequencies f and $0.2f$ are also phase-locked. Thus only the " stored " phase angle of the f or $0.2f$ frequency respectively of the oscillators of the green Slave station and of the Master station can be compared. In this way the lane identification or zone identification within five zones respectively is obtained. Identifications with the other hyperbolic patterns are performed in a similar manner.

The advantage of the Mark 10 lane identification system will be realized immediately from the following discussion: The superposition in phase of the four fixed frequencies $5f$, $6f$, $8f$ and $9f$ result after reduction in the receiver to equal level in the contour shown on Fig. 8. There the frequency f forms a pulse-type peak.

With the normal lane identification system, providing no appreciable phase distortion occurs along the transmission paths, accurate lane identification is obtained. This condition exists within the normal coverage of a Decca chain in daytime, when differential sky wave effects on the individual signals are small, but it may not hold when the amplitude of the

ky wave component exceeds 28 per cent of the ground wave value.[16] In practice this means that, over land, consistently accurate lane identification may extend even during twilight and night to ranges of some 260 km.*

In Mark 10 operation, where the comparison frequency f is formed by four frequencies, i.e. by twice the information content, the amplitude of the sky wave may be up to 44 per cent of the ground wave amplitude in the case of most unfavourable sky wave phase relation, before incorrect lane identification occurs. There liable range of lane identification at night thus is increased to a distance of 450 km from the Master station. In Mark 10 lane identification by phase comparison of the f signals, only that portion exceeding the top line of Fig. 8 is used. The upper limit corresponds to 90 per cent of the total amplitude with superposition in phase. A calculation shows that the 90 per cent limit (amplitude 0.9) is only exceeded by summation of random phase shifts of the four frequencies $5f$, $6f$, $8f$ and $9f$ having an amplitude of 0.25, when to each of the four frequencies a sky wave is added, whose amplitude does not exceed 44 per cent of that of the ground wave, even if the phase angle is most unfavourable.

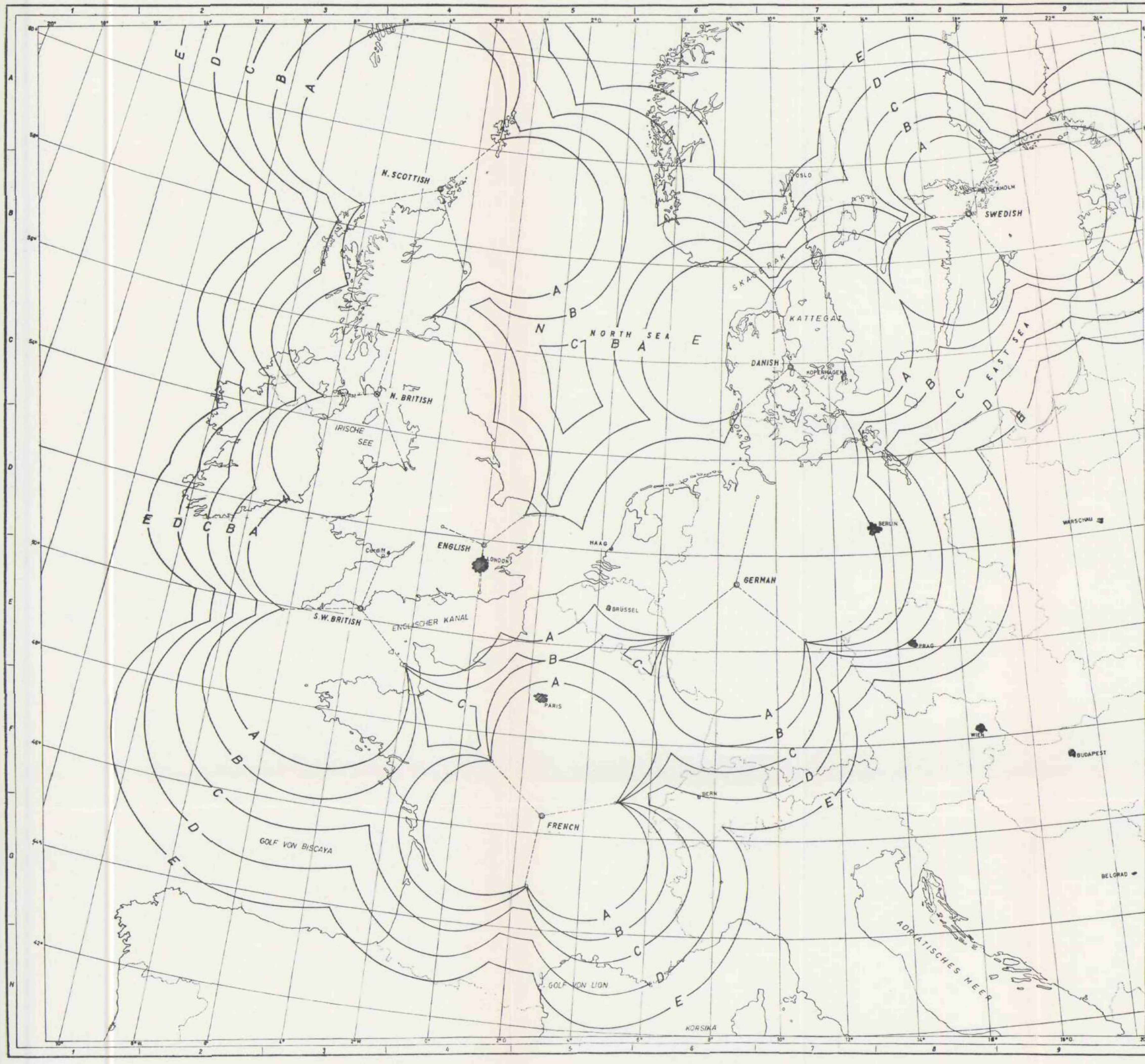
Hence, when the superposition of the four lane identification frequencies $5f$, $6f$, $8f$ and $9f$, which are reduced to a common amplitude, does not exceed the 90 per cent limit, the lane identification is always correct. So when a lane identification can be performed with the Mark 10 receiver at night-time, the lane identification is known to be correct. When the lane identification is accomplished with only two pairs of frequencies, $5f$ and $6f$, or $8f$ and $9f$ respectively, always the instantaneous phase angle is measured independent of the magnitude of the sky wave influence. It is *not* known at night, whether or not the lane identification is correct. The time interval between the peak pulses above 90 per cent of the frequency f, which is stored after each Mark 10 lane identification, is used for the semi-automatic lane identification system. Zone identification and lane identification is accomplished once per minute for all three families of hyperbolae.

The Reasons for the Frequency Range Chosen, Problems of Propagation

The low frequency band around 100 kc/s is most suitable for the Decca system. With *lower* frequencies, the aerial system of the ground stations would necessitate larger investments to obtain the same transmission power. The effective height of the aerial would be decreased with respect to the airborne receiver. These factors together with the higher noise level of the lower frequencies would necessitate a substantial increase in the transmitter power. The use of *higher* frequencies results in attenuation of the ground wave, but on no account a reduction of the sky wave influence. Thus fading would occur at night at increasingly shorter intervals thereby reducing the range. Furthermore, contrary to very high frequencies, the low frequencies descend to the bottom of deep valleys.[9] This is of importance when the Decca system is used in helicopter operations. Extensive studies of the conditions of propagation and phase variations in the 70–130 kc/s band are discussed in refs. 10 and 11.

* If propagation is primarily over sea, longer lane identification ranges are obtained.

Fig. 9



Positional error at sea level at 95 % probability (in nautical miles)

Decca period see diagram A	contour in n.m. (km) A	B	C	D	E
Winter night	1,5 (2,77)	3 (5,5)	x	x	x
Summer night	1 (1,85)	2 (3,7)	4 (7,4)	x	x
Twilight	0,5 (0,93)	1 (1,85)	2 (3,7)	4 (7,4)	8 (14,8)
Half daylight	0,25 (0,46)	0,5 (0,93)	1 (1,85)	2 (3,7)	4 (7,4)
Full daylight	0,25 (0,46)	0,25 (0,46)	0,5 (0,93)	1 (1,85)	2 (3,7)

Table 9a

Note:
A 95 % probability means that as an average only every 20th reading is outside the error limits given.

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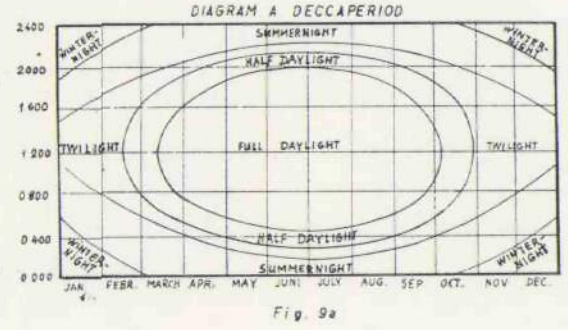


Fig. 9a

Scale 1: 4 000 000
(geographical longitude as dependent upon the geographical latitude)

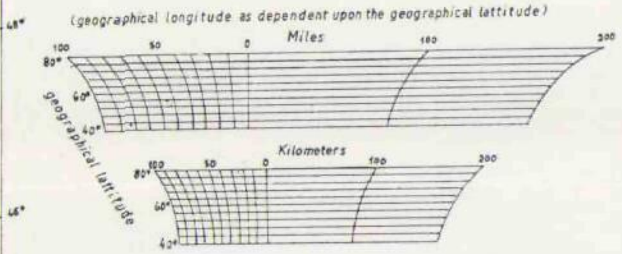


Fig. 9

EFFECTIVE DECCA RANGES AT DIFFERENT RADIAL ERRORS AT 95 % PROBABILITY

Fig. 9. Effective Decca ranges at different radian errors at 95 per cent probability

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3. ACCURACY AND RANGE

The effective range can be stated only when the maximum radius of the 95 per cent circle of uncertainty is given. Assuming the standard deviation on all base lines be $\pm$ 10 m, the range contours at radial errors of different magnitude are calculated as in Section 5, accuracy and range, and illustrated in Fig. 8. The assumption of a base line standard deviation of $\pm$ 10 m is applicable only under favourable conditions. If the waves are propagated over broken terrains, the standard deviation occasionally may be increased by a factor of 4. At night and during the winter season, the propagation conditions are subject to greater variations because of the increased influence of the sky wave. The values of the figure mentioned above remain correct only when the 95 per cent radial error is multiplied by the diurnal and seasonal factors given in the figure [10–14].

The calculated contour corresponds to the real conditions within the triangle formed by the Slave stations. At greater ranges, the reduced field strength, the phase deviation due to increased sky wave influence and, most of all, the correlation beginning at that point (which may assume a value of $\frac{2}{3}$) must be taken into account.

These three influences increase the mean radial error or reduce the area of a given effective range and result in the contours (shown in Fig. 9) in which the mean radial error of A, B, C, D and E (see Table 9a) is not exceeded in 95 per cent of all cases.

The contours were calculated by the Decca Navigator Co. The calculations are based on a standard deviation of $\pm$ 10 m on the baseline. The effective ranges are greater over sea than over land.

Besides accidental errors there are systematic errors, which, if caused by instrumental errors that can be calibrated, are of such a magnitude that they need be taken into account only in special surveying operations.

The instrumental errors of the Master and Slave station comprise deviations of $\pm$ 0.02 lanes of the individual hyperbolae from their nominal values. Such errors are due to variations within the equipment.

The hyperbolae of the Decca chains are calculated for an average and constant velocity of propagation. Hence, deviations from such velocity cause systematic errors. The velocity of propagation is also influenced by the climate and the humidity of the soil. Systematic errors become important close to the coast. The deviations occurring (coast refraction) are indicated on data sheets used in marine navigation.

Detailed studies of the daily and diurnal variations have been made since 1952 by W. Feyer at several observation stations within the coverage of the German Decca chain.[12] These investigations showed that the coarse long-term variations during winter are related statistically to long-term variations in the air temperature. Therefore, it seems possible to apply this correlation caused by the variation in the complex ground conductivity to a systematic correction of radio navigation systems operating in the 100 kc/s region.

Since the areas of equal phase-angle difference are hyperboloids, systematic errors occur at greater altitudes, whose magnitude is particularly great in the proximity of the respective ground stations. This error can be reduced greatly, however, if when flying over a ground station, only such

hyperbolae are used which do not originate from the particular transmitter or the nearest transmitter. This is always possible with the Slave stations and also with the Master station.

4. NAVIGATIONAL AND OPERATIONAL CONSIDERATIONS

Aviation

Different receiver models are available for use in helicopters, jet aircraft and slow civil aircraft. Since the values of the primary radio coordinates indicated by the decometers require plotting on a chart, they cannot be used by the pilot for navigational purposes. Therefore, the flight log was developed for aircraft use, which is generally provided with Decca airborne equipment.

The flight log indicates very accurately and continuously the position within the coverage of a Decca chain (see Fig. 9) and records the track flown.

The Decca system with flight log allows deviation from a rigid airway system. New airways or the re-location of airways requires no alteration of the aids to navigation ; only the flight log charts of the region concerned must be altered. The following advantages are claimed for the use of flight logs :

En route navigation. Better track-keeping on airways, reliable circumnavigation of prohibited areas and danger areas without additional radio navigation facilities, early recognition of wind drift, simple calculation of the ground speed by the automatic entry of time marks on the chart, greater reliability in determining the estimated time of arrival (ETA). The flight log allows changing from one route to another at any time, if the charts were prepared accordingly. Thus the system is highly adaptable to different conditions of operation.

In the terminal control area the accurate position display is likewise advantageous. Holding patterns may be carried out at any point of the coverage, from which the aircraft can perform a timed approach on approachways length is determined by the aircraft speed and the wind direction. Thus the landing rate can be increased. Maintaining discreet approachways, which are entered on the flight charts, requires no R/T traffic. The problems of identification in the case of radar surveillance is simplified in that the pilot always can give his exact position when requested by the control tower. Thus no special identification manoeuvres are necessary.

The flight log can be operated easily. After the preparations prior to flight (joining and inserting the required charts, fixing the Decca coordinates for setting the flight log stylus when a chart change is to be performed) the stylus is placed on the exact position on the chart prior to take-off. When a chart change is required (*en route*) the stylus must be re-set. Simplifications achieved on the Mark 10 receiver or by selecting the proper charts has been discussed above. It is recommended that the correct position displayed be checked by reference to the decometer readings ; if necessary, the stylus should be re-set. Such checks are especially important prior to entry into the terminal control area and prior to the commencement of holding and approach procedures. A combination of letters and numerals has been fixed for each chart, which must be adjusted on the control equipment on take-off or when the chart was changed.

The flight log charts contain all data necessary for the navigation of the aircraft. The flight log charts used normally provide the following information:

(*a*) the airway system;
(*b*) distance in nautical miles from the aerodrome of departure to the terminal airport;
(*c*) arrows indicating north at several points of severely distorted flight log charts;
(*d*) topographic features as necessary from *en route* navigation;
(*e*) information on air traffic control facilities;
(*f*) the lines of two hyperbolic lattices by means of which correct setting of the stylus can be checked.

Reduced signal strength conditions are indicated intermittently by a yellow alarm lamp provided on the flight log.

During 1960 the Decca Navigator Co. developed an " Omnitrac Airborne Computer " for converting continuously the Decca-hyperbola-coordinates into rectangular coordinates in 600 msec. The computer accomplishes all operations which are necessary for immediate track guidance and even for connection to the automatic pilot.

Shipping

The data measured are interpreted on board ships by plotting on Mercator charts which are overprinted with the calculated hyperbolic patterns. Since the shipborne receiver is of the crystal-controlled type and contains the crystals of all the chain frequencies, manipulation is reduced to selecting the required chain. A track plotter has been developed for navigation on shipping lanes; the course made good is plotted on slightly distorted charts.

5. GROUND STATIONS AND AIRBORNE (SHIPBORNE) EQUIPMENT

Ground Stations

Each Master and Slave station comprises:

Transmitting equipment. Three oscillator stages, one fine fixing and one lane identification transmitter output stage each, one additional lane identification transmitter output stage for the purple Slave station, standby transmitter, automatic change-over equipment and incorporated monitoring equipment. Power of each output stage: 2.4 kW, connected load 15 kVA, the average FOB price of a transmitter installation is DM 282,000, and DM 400,000 for Mark 10 Decca.

The aerial equipment of the Master station consists of a self-radiating aerial tower of 100 m in height and an additional standby T-aerial which is 180 m in length and supported on three towers of 48 m in height. The counterpoise of the main aerial tower consists of 120 zinc-plated iron bands each 100 m in length. For the three Slave stations a mobile standby aerial system is provided similar to the standby system of the Master station.

The price of the aerial equipment ranges from 40,000 to 100,000 DM, according to the type required as determined by the local conditions.

At least one monitoring station is required for each chain. The monitoring station is equipped with receiving equipment, indicating and recording instruments which cost 35000 DM.

A set of service valves of a ground station costs 5000 DM. Cubage of each ground station: approximately 1300 m^3. The erection and placing into service requires approximately 500 hr, the commissioning requires approximately 160 hr. The current operating costs of each ground station are:

costs of valves per annum	6200 DM
megawatt-hours per annum	120 for Master 100 for Slaves

Equipment-maintenance costs per annum: approx. 10000 DM.

According to the present technical status, the phase- and frequency-locked transmission is accomplished automatically to the extent of 60 per cent; 40 per cent of manual operation is still required. Three radio mechanics are required for each Slave station for maintenance and trouble shooting.

Since the Master station controls the transmissions of all the Slave stations, five radio mechanics are required for full-day operation of the Master station.

Airborne Equipment

The various requirements of aviation are satisfied by the modern Decca receivers Mark 7, Mark 8, Mark 9 and Mark 10.

All of the above receiver models have in common:

RECEIVING UNIT (straight amplifier circuits, only Mark 10 with superhet-circuit, crystal filters). Decometer group (Mark 8 with three fine fixing decometers and one lane identification meter; Mark 7 lane identification is incorporated on each of the three fine pattern decometers; on Mark 10 lane identification and zone identification are on the fine pattern decometers. The Mark 9 receiver does not normally use decometers, since the output is fed directly to the flight log).

FLIGHT LOG, remote control unit (with pilot lamps) by which all switching on and off operations and the chain selection are performed; the unit is located near the navigator or in the cockpit.

POWER UNIT, and AERIAL with aerial booster.

The FOB price in Great Britain, dimensions, power requirements and special characteristics of the receivers are given in Table 1.

All flight log models have in common: the control, box (chart selection, stylus setting, switching on and off), the mechanical and electrical components of the torque amplifier, the display head and the chart holder. Chart capacity, visible chart area, weight, size, FOB price in Great Britain, power requirements and special characteristics are given in Table 2.

Connections are provided on all receivers for decometer repeaters and flight log repeaters.

The average costs per annum of valves refer to 1000 hr of service and amount to approximately DM 2000. The maintenance costs for the same period amount to approximately DM 3000.

Shipborne Equipment

The Mark 5 receiver has been developed for shipborne operation. It consists of a receiver unit (straight amplifier circuits, with quartz filters, with change-over facility to nine chains), one display unit (three fine decometers, one lane identification decometer with six-armed vernier pointer and zone sector indicator), vertical wire aerial, and, if required, with rotary converter supplying 220–230V, 50 c/s and 250W; weight 42 kg. The weight of the receiver and display units is 45 kg. A decometer repeater for marine receivers is available (FOB price DM 3000, weight 14.5 kg). The Mark 5 receiver is provided with connections for the track plotter which costs (FOB) DM 11,800 and weighs 61 kg.

The Mark 5 receiver costs DM 22,500 (FOB).

Table 1. Frequency-Groups of Decca-chains in operation to Dec. 1960

Chain No.	*Chain*	*Master (kHz)*	*Red (kHz)*	*Green (kHz)*	*Purple (kHz)*
1(*b*)*	S.W. British	84.280	112.373	126.420	70.233
1(*c*)	South Persian Gulf	84.285	112.380	126.4275	70.2375
2(*b*)*	E. Newfoundland	84.461	112.615	126.691	70.384
3(*b*)*	N.W. British	84.645	112.860	126.967	70.537
4(*b*)	Swedish	84.825	113.100	127.238	70.688
5(*b*)*	English	85.000	113.333	127.500	70.833
5(*c*)	North Persian Gulf	85.005	113.340	127.5075	70.8375
6(*b*)	W. Newfoundland	85.180	113.573	—	70.983
6(*c*)	N. Scottish	85.185	113.580	127.777	70.987
7(*b*)*	Danish	85.365	113.820	128.047	71.137
7(*c*)	Nova Scotia	85.370	113.827	128.055	71.142
8(*b*)*	French	85.545	114.060	128.317	71.287
9(*b*)	German	85.720	114.293	128.580	71.433
9(*c*)	Quebec	85.725	114.300	128.587	71.437

* Chain is installated for Mark 10.

Table 2. Prices, Measures and special characteristics

Receiving Equipment	*Component*	*FOB Price in the U.K. (in DM)*	*Weight (kg)*	*Overall Dimensions (cm) (width × depth × height)*	*Power Consumption*	*Special Characteristics*
Mark 7	Aerial booster 308	494	0.5	9.7 × 15.0 × 6.4		Electronic flywheel facility for preventing lane loss
	Receiver 276	11,321	15.8	40.0 × 39.7 × 29.7		
	Three Decometers 273	3572	1.4	11.3 × 7.6ϕ	24V	
	Control box 278	635	0.5	14.1 × 5.6 × 5.6ϕ	11.5A	
	Power supply 277	1950	10.5	14.5 × 15.0 × 19.8		
	Total	17,972				
Mark 8	Aerial booster 308	494	0.5	9.7 × 15.0 × 6.4		
	Receiver 351	11,057	16.0	39.0 × 40.0 × 20.0		
	Decometers: Normally one red, one green, one purple 274/5 lane identification	2428 593	fine 0.55 coarse 0.73	9.5 × 7.3ϕ 14.0 × 7.3ϕ		Can be provided with repeater unit
	Control box 356	217	0.5	14.5 × 6.3 × 7.1	24V	
	Power supply 277 Electro-mechanical flywheel unit (repeater unit)	1950 9929	10.35	14.6 × 39.69 × 19.68	12A	
	Total *with* Repeater unit *without* Repeater unit	26,668 16,739				

Table 2 (continued)

Receiving Equipment	*Component*	*FOB Price in the U.K. (in DM)*	*Weight (kg)*	*Overall Dimensions (cm) (width × depth × height)*	*Power Consumption*	*Special Characteristics*
Mark 9	Aerial booster 308	494	0.5	9.7 × 15.0 × 6.4		
	Receiver 744	5957	5.6	15.2 × 20.3 × 31.8		
	Control box 751	300	2.2	31.8 × 22.5 × 3.5	24V	Requires little space its weight is low, range is limited
	Computer and power pack for receiver and computer 395	4465	6.12	15.2 × 20.3 × 31.75	11A	
	Display head 720	3278	2.15	43.2 × 17.9 × 3.6		
	Total	14,494				
Mark 10	Aerial booster 308	494	0.5	9.7 × 15.0 × 6.4		Automatic lane identification, automatic lane adjustment, zone identification within five zones. Increased range
	Receiver 800	18,213		60.3 × 39.4 × 19.7		
	Decometers	3525				
	Control box 801	1293		14.4 × 9.5 × 7.5		
	Power Supply 859	2056	9.98	20.3 × 29.7 × 19.7		
	Total	25,581				

Table 3. Flight Log Equipment

Equipment/Model	*Size of Visible Chart Area (cm × cm)*	*No. of Chart per Roll*	*Weight (kg)*	*Overall Dimension width × depth × height (cm × cm × cm)*	*FOB Price (DM)*	*Special Characteristics*
Display head 331	25 × 20	until 12	0.45	30.0 × 14.0 × 14.3	3478	Suitable for computers 750, 722
Display head 720	12.7 × 38				3278.25	Suitable for computer 395
Computer 750			7.4	12.6 × 20.0 × 40.6	8935.75	Fed from receiver
Computer 722			7.4	12.6 × 20.0 × 40.6	8935.75	Fed from receiver
Computer 395			6.12	15.2 × 20.3 × 31.7	8935.75	Fed from receiver
Control box 332			1.2	13.7 × 14.6 × 6.4	893	Scale selection, selection of the hyperbolic patterns, remote control

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